CLAIMS

1. A satellite-based positioning receiver with correction of inter-satellite cross-correlation errors, the receiver comprising a correlation channel Cii of order i per satellite received, with i=1,2,..N, N being the number of satellites received (Sat1, Sat2,...SatN), each correlator channel Cii having:

- a carrier correlation path (12), in-phase and quadrature, between the signal received (Sr, Br) and two respective local quadrature carriers (sine, cosine) generated by an oscillator with digital control of carrier (NCO p);

- a code correlation path (16) based on the signals I, Q output by the in-phase and quadrature carrier correlation path, with the local codes of the satellite received, provided by a digital generator of local codes;

- an integrator (20) for providing, for each local code, signals I_c Q_c at the output of the correlator channel Cii of the satellite received, c designating each of the local codes,

characterized in that it comprises, for each correlator channel Cii of the satellite received as many additional correlator channels Cix as additional satellites received with x=1,2,...N and x different from i, and in that the local codes of the satellite received are correlated with the local codes of the other additional satellites Cix.

2. The satellite-based positioning receiver as claimed in claim 1, characterized in that the local codes of the satellite received for the code correlation path (16, 56) are a punctual code and a delta code, the code correlation path in fact comprising two correlation paths:

- a punctual path (I_P,Q_P),
- a delta path (I_Δ,Q_Δ).

3. The satellite-based positioning receiver as claimed in claim 1, characterized in that the local codes of the satellite received for the code correlation path (16, 56) are a punctual code, an early code and a late code, and in that the integrator (20) provides signals $(I_P, Q_P, I_A, Q_A, I_R, Q_R)$, the code correlation path comprising three correlation paths:

- an early path (I_A, Q_A),
- a punctual path (I_P, Q_P), and
- a late path (I_R, Q_R), the delta path being reconstituted from the early path minus the late path by the formulae:

$$I_\Delta = I_A - I_R$$

$$Q_\Delta = Q_A - Q_R$$

4. The satellite-based positioning receiver as claimed in either of claims 1 or 2, characterized in that it comprises N reception subsets Si, each subset Si of rank i having the correlator channel Cii of the signal of the satellite received of order i and N-1 additional correlator channels Ci1,Ci2,..Cix,...CiN for the additional satellites received, x = 1,2,...N and x different from i, each received signal correlator channel Cii being driven by its reception input (Er) by the signal received (Sr), each of the additional correlator channels of a subset Si, receiving respectively, on the one hand, at its received-signal input (Er), a local signal Slox resulting from the modulation of the local carrier (F_{1x}) by the punctual local code (Cpx) of the correlator channel Cxx of the satellite received of order x, and on the other hand, at its local carrier and local codes local inputs, the respective local quadrature carriers (F_{II}, F_{Qi}) and the local codes (Cpi and Δi) of the correlator channel (Cii) of the signal received from the satellite of order i.

5. The satellite-based positioning receiver as claimed in claim 4, characterized in that each correlator channel Cix of rank x in the subset Si, with x=1,2,...N, comprises:

- the in-phase and quadrature carrier correlation path (12) between the signal received and two respective quadrature local carriers (sine, cosine);

- the code correlation path (16) based on the signals I, Q at the output of the in-phase and quadrature carrier correlation path with the punctual (Cpi) and delta (Δi) local codes of the satellite of order i;

- an integrator (20) for providing signals I_{Pix}, $I_{\Delta ix}$, Q_{Pix}, $Q_{\Delta ix}$ at the output of the correlator channel,

the subset Si furthermore comprising:

- an oscillator with digital control of carrier (OPi)(NCO p) for providing local carriers F_{Ii}, F_{Qi} for the N correlators of the subset Si considered and a digital generator of local codes (OCi) for providing the local codes, punctual (Cpi) and delta (Δi), for the N correlators of the subset Si considered;

- a multiplier Mi providing for the other subsets Sx of the receiver a local signal (Sloi), resulting from the modulation of the local carrier (F_{Ii}) by the punctual code (Cpi) of the subset considered Si, so as to perform the correlation of the code modulated by the carrier of the satellite considered with the codes modulated by the carriers of the other satellites;

- a correlation corrector CRi providing on the basis of the signals I_{Pix}, $I_{\Delta ix}$, Q_{Pix}, $Q_{\Delta ix}$ at the output of the N correlator channels of the subset considered (Si), x taking, for these signals I_{Pix}, $I_{\Delta ix}$, Q_{Pix}, $Q_{\Delta ix}$, the values 1 to N, and signals I_{Pxx}, I_{Qxx} output by the received-signal correlator channels Cxx of the other subsets Sx, corrected signals I_{Pi}', $I_{\Delta i}'$, Q_{Pi}', $Q_{\Delta i}'$;

- a carrier discriminater DPi providing through a carrier loop corrector CBPi a control signal Vcpi for the oscillator with digital control of carrier (NCO p) so as to provide local carriers (F_{Ii}, F_{Qi}) for the N

correlators of the subset Si considered;

- a code loop discriminator DCi providing through a code loop corrector CBCi a control signal Vcci for the digital generator of local codes (OCi) (NCO c) for providing the local codes, punctual (Cpi) and delta (Δi) for the N correlators of the subset Si considered.

6. The satellite-based positioning receiver as claimed in one of claims 1 to 5, characterized in that it comprises a first (S1), a second (S2) and a third (S3) reception subset having three correlator channels each for receiving three satellites.

7. The satellite-based positioning receiver as claimed in claim 6, characterized in that the first (S1), second (S2), and third subsets (S3) of the receiver respectively comprise a first (C11), a second (C22) and a third (C33) signal correlator channels driven at their reception input (Er) by the signal Sr received by the receiver, each subset furthermore comprising:

- in the first subset (S1), two other additional correlator channels C12 and C13 driven respectively at their reception input by local signals Slo2, Slo3 emanating respectively from a multiplier M2 and from a multiplier M3, the signal Slo2 resulting from the modulation of the local carrier F_{I2} by the punctual code Cp_2 of the second satellite and the signal Slo3 resulting from the modulation of the local carrier F_{I3} by the punctual code Cp_3 of the third satellite;

- in the second subset (S2), two other additional correlator channels C21 and C23 driven respectively at their reception input by local signals Slo1, Slo3 emanating respectively from a multiplier M1 and from a multiplier M3, the signal Slo1 resulting from the modulation of the local carrier F_{I1} by the punctual code Cp_1 of the first satellite;

- in the third subset (S3), two other additional correlator channels C31 and C32 driven at their

reception input by the local signals Slo1, Slo2 emanating respectively from the multipliers M1 and M2;

each correlator of each of the subsets comprising:

- the in-phase and quadrature carrier correlation path (12) between the signal at their reception input and two respective quadrature local carriers (sine, cosine), F_{I1}, F_{Q1} for the first subset (S1), F_{I2}, F_{Q2} for the second (S2) and F_{I3}, F_{Q3} for the third (S3), these carriers being generated respectively, for each of the subsets (S1,S2 and S3) by a first (OP1), a second (OP2) and a third (OP3) oscillators with digital control of carrier (NCO p);

- the code correlation path (16) based on the signals I, Q at the output of the in-phase and quadrature carrier correlation path with the local codes, punctual (Cp1,Cp2,Cp3) and delta (Δ1,Δ2,Δ3) of the satellites respectively of order 1, 2, 3, provided by a digital generator of local codes (OC1, OC2 and OC3) respectively for each subset;

- an integrator per correlator channel for respectively providing signals $I_{P1x}, I_{\Delta 1x}, Q_{P1x}, Q_{\Delta 1x}$ at the output of the correlator channel C1x; $I_{P2x}, I_{\Delta 2x}, Q_{P2x}, Q_{\Delta 2x}$ at the output of the correlator channel C2x and $I_{P3x}, I_{\Delta 3x}, Q_{P3x}, Q_{\Delta 3x}$ at the output of the correlator channel C3x, with x=1,2,3,

each subset of three correlators comprising:

- a corrector (Cr1,Cr2,Cr3) of correlations providing on the basis of the signals $I_{Pix}, I_{\Delta ix}, Q_{Pix}, Q_{\Delta ix}$, with i=1,2,3, at the output of the N correlator channels of the subset considered (S1,S2,S3) and of the signals I_{Pxx}, Q_{Pxx}, at the output of the received-signals correlator channels (of order x) of the other subsets (Sx), of the corrected signals $I_{P1}', I_{\Delta 1}', Q_{P1}', Q_{\Delta 1}'$ at the output of the first corrector Cr1, $I_{P2}', I_{\Delta 2}', Q_{P2}', Q_{\Delta 2}'$ at the output of the second corrector Cr2, $I_{P3}', I_{\Delta 3}', Q_{P3}', Q_{\Delta 3}$ at the output of the third corrector Cr3, the signals I_{Pxx}, Q_{Pxx} at the output of the received-signal correlator channels, driving the correctors, being the signals

$I_{P22}, I_{P33}, Q_{P22}, Q_{P33}$ for the corrector Cr1, $I_{P11}, I_{P33}, Q_{P11}, Q_{P33}$ for the corrector Cr2 and $I_{P11}, I_{P22}, Q_{P11}, Qp_{22}$ for the corrector Cr3,

- a carrier discriminator (DP1,DP2,DP3) respectively providing through a carrier loop corrector (CBP1,CBP2,CBP3) a control signal (Vcp1,Vcp2,Vcp3) for the respective oscillator with digital control of carrier (OP1,OP2,OP3) (NCO p) so as to provide local carriers F_{I1}, F_{Q1}, for the first subset (S1), F_{I2}, F_{Q2} for the second subset (S2) and F_{I3}, F_{Q3} for the third subset (S3);

- a code loop discriminator (DC1,DC2,DC3) respectively providing through a code loop corrector (CBC1,CBC2,CBC3) a respective control signal Vcc1,Vcc2,Vcc3 for the digital generator of local codes (OC1,OC2,OC3) (NCO c) so as to provide the local codes, punctual and delta (Cp1,Δ1) for the three correlators of the first subset (S1), (Cp2,Δ2) for the three correlators of the second subset (S2) and (CP3,Δ3) for the three correlators of the third subset (S3).

8. The satellite-based positioning receiver as claimed in either of claims 6 or 7, characterized in that it is configured to perform the following corrections:

for the first satellite Sat1:

- on the punctual path:

$$I_{P1}' = I_{P11} - I_{P22} \,.\, I_{P12} \,.\, 2/T - I_{P33} \,.\, I_{P13} \,.\, 2/T$$
$$Q_{P1}' = Q_{P11} - I_{P22} \,.\, Q_{P12} \,.\, 2/T - I_{P33} \,.\, Q_{P13} \,.\, 2/T$$

- on the delta path:

$$I_{\Delta1}' = I_{\Delta11} - I_{P22} \,.\, I_{\Delta12}\, 2/T - I_{P33} \,.\, I_{\Delta13} \,.\, 2/T$$
$$Q_{\Delta1}' = Q_{\Delta11} - I_{P22} \,.\, Q_{\Delta12}\, 2/T - I_{P33} \,.\, Q_{\Delta13} \,.\, 2/T$$

- i.e. in complex notation, with $j^2=-1$:

$$I_{P1}'+jQ_{P1}'=I_{P11}+jQ_{P11}-I_{P22}\,(I_{P12}+jQ_{P12}).\,2/T-I_{P33}\,(I_{P13}+jQ_{P13}).\,2/T$$
$$I_{\Delta1}'+jQ_{\Delta1}'=I_{\Delta11}+jQ_{\Delta11}-I_{P22}\,(I_{\Delta12}+jQ_{\Delta12}).\,2/T-I_{P33}\,(I_{\Delta13}+jQ_{\Delta13}).\,2/T$$

with $\frac{T}{2}=\int_0^T(local\,signal(t))^2\,dt$, T integration period of the integrator (20).

9. The satellite-based positioning receiver as claimed in one of claims 5 to 8, characterized in that in the case where the local carriers are not entirely in phase with the carriers received it is shown that:

for the first satellite Sat1:

- on the punctual path:

$$I_{P1}'=I_{P11}-(I_{P22}\,.\,I_{P12}-Q_{P22}\,.\,Q_{P12}).\,2/T-(I_{P33}\,.\,I_{P13}-Q_{P33}\,.\,Q_{P13}).\,2/T$$
$$Q_{P1}'=Q_{P11}-(I_{P22}\,.Q_{P12}+Q_{P22}\,.\,I_{P12}).\,2/T-(I_{P33}\,.\,Q_{P13}+Q_{P33}\,.\,I_{P13}).\,2/T$$

- on the delta path:

$$I_{\Delta1}'=I_{\Delta11}-(I_{P22}\,.\,I_{\Delta12}-Q_{P22}\,.\,Q_{\Delta12}).\,2/T-(I_{P33}\,.\,I_{\Delta13}-Q_{P33}\,.\,Q_{\Delta13}).\,2/T$$
$$Q_{\Delta1}'=Q_{\Delta11}-(I_{P22}\,.Q_{\Delta12}+Q_{P22}\,.\,I_{\Delta12}).\,2/T-(I_{P33}\,.\,Q_{\Delta13}+Q_{P33}\,.\,I_{\Delta13}).\,2/T$$

- i.e. in complex notation, with $j^2=-1$:

$$I_{P1}'+jQ_{P1}'=I_{P11}+jQ_{P11}-(I_{P22}+jQ_{P22})(I_{P12}+jQ_{P12})2/T-(I_{P33}+jQ_{P33})(I_{P13}+jQ_{P13})2/T$$
$$I_{\Delta1}'+jQ_{\Delta1}'=I_{\Delta11}+jQ_{\Delta11}-(I_{P22}+jQ_{P22})(I_{\Delta12}+jQ_{\Delta12})2/T-(I_{P33}+jQ_{P33})(I_{\Delta13}+jQ_{\Delta13})2/T$$

for the second satellite Sat2:

$$I_{P2}'+jQ_{P2}'=I_{P22}+jQ_{P22}-(I_{P11}+jQ_{P11})(I_{P21}+jQ_{P21})2/T-(I_{P33}+jQ_{P33})(I_{P23}+jQ_{P23})2/T$$
$$I_{\Delta2}'+jQ_{\Delta2}'=I_{\Delta22}+jQ_{\Delta22}-(I_{P11}+jQ_{P11})(I_{\Delta21}+jQ_{\Delta21})2/T-(I_{P33}+jQ_{P33})(I_{\Delta23}+jQ_{\Delta23})2/T$$

and in that for the third satellite Sat3:

$$I_{P3}'+jQ_{P3}'=I_{P33}+jQ_{P33}-(I_{P11}+jQ_{P11})(I_{P31}+jQ_{P31})2/T-(I_{P22}-jQ_{P22})(I_{P32}+jQ_{P32})2/T$$
$$I_{\Delta3}'+jQ_{\Delta3}'=I_{\Delta33}+jQ_{\Delta33}-(I_{P11}+jQ_{P11})(I_{\Delta31}+jQ_{\Delta31})2/T-(I_{P22}-jQ_{P22})(I_{\Delta32}+jQ_{\Delta32})2/T$$

and in that generally:

- on the punctual path:

$$I_{Pi}' = I_{Pii} - \Sigma_{\text{on x different from i}} \left(I_{Pxx} \, . \, I_{Pix} - Q_{Pxx} \, . \, Q_{Pix} \right). \, 2/T$$
$$Q_{Pi}' = Q_{Pii} - \Sigma_{\text{on x different from i}} \left(I_{Pxx} \, . Q_{Pix} + Q_{Pxx} \, . \, I_{Pix} \right). \, 2/T$$

- on the delta path:

$$I_{\Delta i}' = I_{\Delta ii} - \Sigma_{\text{on x different from i}} \left(I_{Pxx} \, . \, I_{\Delta ix} - Q_{Pxx} \, . \, Q_{\Delta ix} \right). \, 2/T$$
$$Q_{\Delta i}' = Q_{\Delta ii} - \Sigma_{\text{on x different from i}} \left(I_{Pxx} \, . Q_{\Delta ix} + Q_{Pxx} \, . \, I_{\Delta ix} \right). \, 2/T$$

i.e. in complex notation, with $j^2=-1$:

$$I_{Pi}' + j\, Q_{Pi}' = I_{Pii} + j\, Q_{Pii} - \Sigma_{\text{on x different from i}} (I_{Pxx} + jQ_{Pxx})(I_{Pix} + jQ_{Pix}) 2/T$$
$$I_{\Delta i}' + j\, Q_{\Delta i}' = I_{\Delta ii} + j\, Q_{\Delta ii} - \Sigma_{\text{on x different from i}} (I_{Pxx} + jQ_{Pxx})(I_{\Delta ix} + jQ_{\Delta ix}) 2/T$$

10. The satellite-based positioning receiver as claimed in one of claims 1 to 5, characterized in that each correlator channel (50) operates with a signal received (Br) in baseband, in the form of two signals I and Q in quadrature.

11. The satellite-based positioning receiver as claimed in claim 10, characterized in that the baseband correlator channel (50) comprises an in-phase and quadrature correlation path (52) between the baseband signal received, in the form of two signals I and Q in quadrature, and two respective local carriers F_I, F_Q, these local quadrature carriers (sine, cosine) being generated by an oscillator with digital control of carrier (54) (NCO p) of the receiver.

12. The satellite-based positioning receiver as claimed in claim 11, characterized in that the baseband

receiver comprises N reception subsets for N satellites received, each subset Si of rank i, with i=1,2,3,...N, comprises a correlator channel Cii for a satellite received Sati and N-1 additional correlators Ci1,Cix,...CiN for the additional satellites Sat1,Satx,...SatN, with x different from i, the correlator channel Cii and the additional channels of each subset Si furthermore comprising:

- a first MIi and a second MQi multipliers providing for the other subsets of the receiver a first SLIi and a second SLQi local signals resulting from the modulation of the quadrature signals F_{Qi} and FIi of the local carrier by the punctual code Cpi of the subset considered, so as to perform the correlation of the code modulated by the carrier of the satellite considered with the codes modulated by the carrier of the other satellites.

13. The satellite-based positioning receiver as claimed in one of claims 10 to 12, characterized in that it is configured to perform the following corrections:

for the first satellite Sat1:

$$I_{P1}' + jQ_{P1}' = I_{P11} + jQ_{P11} - (I_{P22} + jQ_{P22})(I_{P12} + jQ_{P12})/T - (I_{P33} + jQ_{P33})(I_{P13} + jQ_{P13})/T$$

$$I_{\Delta 1}' + jQ_{\Delta 1}' = I_{\Delta 11} + jQ_{\Delta 11} - (I_{P22} + jQ_{P22})(I_{\Delta 12} + jQ_{\Delta 12})/T - (I_{P33} + jQ_{P33})(I_{\Delta 13} + jQ_{\Delta 13})/T$$

14. The satellite-based positioning receiver as claimed in one of claims 3 to 13, characterized in that the delta path is reconstituted at the output of the correlators by the formulae:

$$I_{\Delta ix} = I_{Aix} - I_{Rix}$$

$$Q_{\Delta ix} = Q_{Aix} - Q_{Rix}$$

15. The satellite-based positioning receiver as claimed in one of claims 1 to 13, characterized in

that, to economize on correlators, the cross-correlations are calculated by:

- for the first satellite Sat1, by $(I_P, I_\Delta, Q_P, Q_\Delta)_{12}$ and $(I_P, I_\Delta, Q_P, Q_\Delta)_{13}$ in addition to $(I_P, I_\Delta, Q_P, Q_\Delta)_{11}$

$$I_{P1}' + jQ_{P1}' = I_{P11} + jQ_{P11} - (I_{P22} + jQ_{P22})(I_{P12} + j\,Q_{P12})/T - (I_{P33} + j\,Q_{P33})(I_{P13} + jQ_{P13})/T$$
$$I_{\Delta 1}' + jQ_{\Delta 1}' = I_{\Delta 11} + jQ_{\Delta 11} - (I_{P22} + jQ_{P22})(I_{\Delta 12} + jQ_{\Delta 12})/T - (I_{P33} + jQ_{P33})(I_{\Delta 13} + jQ_{\Delta 13})/T$$

- for the second satellite Sat2, by $(I_P, I_\Delta, Q_P, Q_\Delta)_{23}$ in addition to $(I_P, I_\Delta, Q_P, Q_\Delta)_{22}$

$$I_{P2}' + jQ_{P2}' = I_{P22} + jQ_{P22} - (I_{P11} + jQ_{P11})(I_{P12} - jQ_{P12})/T - (I_{P33} + jQ_{P33})(I_{P23} + jQ_{P23})/T$$
$$I_{\Delta 2}' + jQ_{\Delta 2}' = I_{\Delta 22} + jQ_{\Delta 22} + (I_{P11} + jQ_{P11})(I_{\Delta 12} - jQ_{\Delta 12})/T - (I_{P33} + jQ_{P33})(I_{\Delta 23} + jQ_{\Delta 23})/T$$

and in that for the third satellite Sat3, nothing is calculated in addition to $(I_P, I_\Delta, Q_P, Q_\Delta)_{33}$

$$I_{P3}' + jQ_{P3}' = I_{P33} + jQ_{P33} - (I_{P11} + jQ_{P11})(I_{P13} - jQ_{P13})/T - (I_{P22} + jQ_{P22})(I_{P23} - jQ_{P23})/T$$
$$I_{\Delta 3}' + jQ_{\Delta 3}' = I_{\Delta 33} + jQ_{\Delta 33} + (I_{P11} + jQ_{P11})(I_{\Delta 13} - jQ_{\Delta 13})/T + (I_{P22} + jQ_{P22})(I_{\Delta 23} - jQ_{\Delta 23})/T$$

and in that by generalizing t, for $x > i$:

$$I_{Pxi} = + I_{Pix}$$
$$Q_{Pxi} = - Q_{Pix}$$
$$I_{\Delta xi} = - I_{\Delta ix}$$
$$Q_{\Delta xi} = + Q_{\Delta ix}$$

16. The satellite-based positioning receiver as claimed in one of claims 1 to 15, characterized in that in order to improve the accuracy of the estimation of the complex amplitude of the signals received respectively from the satellites i, the terms I_{Pii} and Q_{Pii} in the formulae are replaced with the terms I_{Pi}' and Q_{Pi}', the formulae then becoming:

$$I_{Pi}' + j\,Q_{Pi}' = I_{Pii} + j\,Q_{Pii} - \Sigma_{\text{on x different from i}}\ (I_{Px}' + jQ_{Px}')(I_{Pix} + jQ_{Pix})2/T$$
$$I_{\Delta i}' + j\,Q_{\Delta i}' = I_{\Delta ii} + j\,Q_{\Delta ii} - \Sigma_{\text{on x different from i}}\ (I_{Px}' + jQ_{Px}')(I_{\Delta ix} + jQ_{\Delta ix})2/T$$

17. The satellite-based positioning receiver as claimed in claim 16, characterized in that, at each iteration of the calculation, the corrected terms I_{Pi}' and Q_{Pi}' of the previous iteration are used, initializing the calculation with uncorrected terms I_{Pii} and Q_{Pii}, after the acquisition and convergence phase:

$$(I_{Pi}' + j\,Q_{Pi}')_n = (I_{Pii} + j\,Q_{Pii})_n - \Sigma_{\text{on x different from i}}\ (I_{Px}' + jQ_{Px}')_{n-1} . (I_{Pix} + jQ_{Pix})_n . 2/T$$
$$(I_{\Delta i}' + j\,Q_{\Delta i}')_n = (I_{\Delta ii} + j\,Q_{\Delta ii})_n - \Sigma_{\text{on x different from i}}\ (I_{Px}' + jQ_{Px}')_{n-1} . (I_{\Delta ix} + jQ_{\Delta ix})_n . 2/T$$

18. The satellite-based positioning receiver as claimed in any one of claims 1 to 17, characterized in that when the signal received is filtered (limited spectrum), the same filtering is applied to the local signals.

19. The satellite-based positioning receiver as claimed in one of claims 1 to 18, characterized in that a first satellite is acquired, without correction, by a conventional open-loop search process, in that on completion of this process we switch to tracking, we deduce therefrom the local signal of this first satellite and we correct the cross-correlations on the other channels in the search phase (in open loop) and in that each time a new satellite is acquired and tracked, we calculate and we apply the cross-correlation corrections in respect of the measurements of all the other satellites already tracked.